ELEMENTARY
ELECTRICAL TESTING

MONOGRAPH 2
JOINT COMMITTEE SERIES
NATIONAL EDUCATION ASSOCIATION EDITION

CONTRIBUTED BY THE TECHNICAL STAFF OF THE

WESTON ELECTRICAL INSTRUMENT CO.

NEWARK, N. J.

THE JOINT COMMITTEE MONOGRAPH SERIES

The following is a list of Monographs written or being written by the technical staff of the manufacturers mentioned, and issued in co-operation with the Joint Committee on Physics. These Monographs are intended to convey to teachers the point of view of men of affairs as to the principles and facts worth teaching to high school students *in each specialty*.

1. **Announcement.**

2. **Elementary Electrical Testing.**
   Weston Electrical Instrument Company, Newark, N. J.

3. **Edison Storage Batteries.**
   The Edison Storage Battery Company, Orange, N. J.

4. **Hydraulic Machinery.**
   Gould Pump Company, Seneca Falls, New York.

5. **Mechanics of the Sewing Machine.**
   Singer Sewing Machine Co., Singer Building, New York City.

Others are projected.

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ARGUMENT

THIS monograph is prepared as evidence of our belief in the new movement to make education more practical. The Weston Electrical Instrument Company is convinced that the public high school instructors desire to use pedagogic material drawn from real life and prefer to perform laboratory experiments which teach the fundamentals of science as far as possible with commercial equipment, such as the student will later use or see used, and with which he will later be expected to be familiar.

Assured that teachers want to know what technical men in the industries believe to be fundamental, we have prepared brief suggestions relating to the preparation of a course in electrical measurements. Representatives of our house have been observing the work of schools for several years. In issuing this monograph, we have consulted authorities on pedagogics. We have also received the advice of school men and have then printed such matter as appealed to our judgment.

Some of the suggestions offered may be beyond the present scope of high school physics, although extremely elementary from our standpoint.

Since this is neither presented as a text book, nor offered as a complete outline of a course of study, but merely contains material offered for consideration, it is probable that, as this movement progresses, exercises which are at present too advanced may later be acceptable and even necessary.

Exercises credited to authors of text books have in some instances been abbreviated but not altered in detail, even though in our judgment and in the judgment of members of the Joint Committee changes could well be made. We have, however,

appended our opinions when we differed considerably with the author, or believed suggestions were appropriate.

We hereby express our thanks to the authors and publishers who permitted us to quote from their works.

We wish to acknowledge our indebtedness to the members of the Joint Committee on Physics who have advised us in both the general plan of the monograph and in the selection and arrangement of the material. All of our suggestions which were adjudged by the committee members to be impracticable under existing conditions pertaining to schools have been eliminated. However, every effort has been made to make this monograph represent the judgment of our Staff, rather than that of the educators consulted.

WESTON ELECTRICAL INSTRUMENT COMPANY.

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SUBJECTS

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ELEMENTARY ELECTRICAL TESTING

THE EXTENSIVE USE OF ELECTRICAL ENERGY IN NUMEROUS INDUSTRIES

In re-outlining the course of study in high schools, due consideration should be given to the fact that changes in the relative importance of certain industries have recently taken place, and that these changes affect both the home and the civic life of our people in various communities.

The new census gives figures to support the statement that electrical industries are economically more important than the chemical industries in point of the number of wage-earners employed and in the value of the product manufactured each year.

It is estimated that ten billion dollars are now invested in electrical industries. About one-fourth of this represents the capital invested in power developments of a semi-public nature.

The educational significance of these facts is two-fold.:

First. In emphasizing that *more attention must be given by instructors to the industrial applications of electricity, and to physics generally.*

Second. In the direct answer which they give to the question as to what constitutes *practical* ideas from the business man's point of view. We will elaborate this point. The greater portion of this tremendous investment is dependent upon the maintenance of circuits having a pressure of 110 volts or over. Accordingly the first things that students should learn are the facts concerning these circuits. For developing means of teaching these and other facts the country is dependent upon its educators. It is from teachers only that the student may obtain comprehen-

sive ideas relating to the materials, arrangement and methods of distribution of electrical circuits. Just as the water and gas mains, with their innumerable outlets and ramifications, supply a city with two necessities, the electrical conductors give us access to an agent—a source of energy—which has become more necessary to us than gas, and in frequent instances is almost as indispensable as water. And this agent, this source of energy, is an electric *current*.

It seems logical and proper, therefore, that a course in elementary electrical measurements should begin with the consideration of the subject from the standpoint of current.

CURRENT

The following exercise, published in the Manual of Fuller and Brownlee,* Experiment 77, is here given in part as an illustration of a method of teaching current distribution.

EXPERIMENT I

RESISTANCE AND CURRENT IN A DIVIDED CIRCUIT

Object. To compare (*a*) the currents in the branches of a divided circuit with the resistance of those branches; (*b*) the total resistance with the resistance of the branches.

Apparatus. Lamp board like that shown in Fig. 1; 32-candle-power lamps to fill board; 3 ammeters; voltmeter, with connecting wires; connections to 110 volts D.C. circuit.

Experimental. Proper connections for a circuit of two branches, like that shown in Fig. 1, are to be made. The resistance in each branch of the circuit consists of an equal number of similar incandescent lamps, connected in parallel. The ammeters are so connected that the total current through both branches can be read and also the individual current in each branch. The terminals of a voltmeter, which is not shown, are to be connected to the terminals of any portion of the circuit whose resistance is desired.

* Published by Allyn & Bacon, Boston.

All the lamps on both sides are to be turned on and reading of each ammeter recorded. The voltmeter is then connected in succession to the terminals of each branch circuit and to the terminals of the combined circuit and the readings obtained recorded in tabular form near the top of the left-hand page. All the lamps but one on one branch are then turned out, leaving all the lamps in the other branch of the circuit burning. Readings of the voltmeter and ammeters are taken and recorded
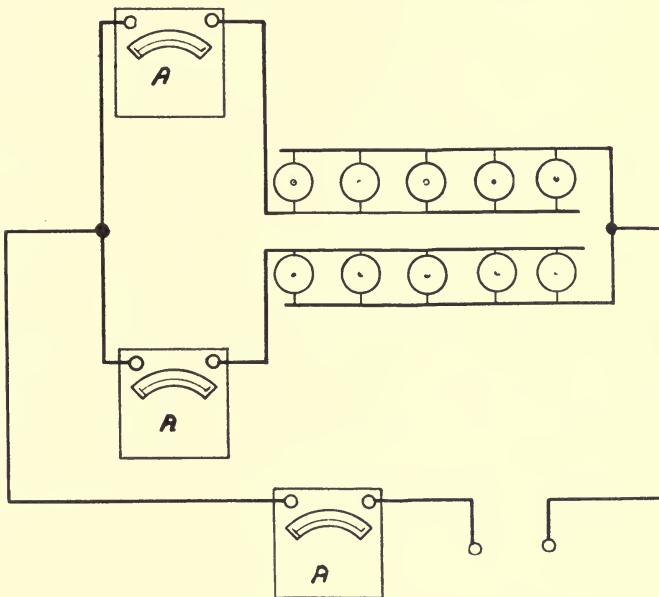
Fig. 1.—Lamp Board, Ammeters and Connections.

as before. Make the following additional combinations in the two branches and record the results: 2 lamps and 3 lamps; 2 lamps and 4 lamps; 2 lamps and 5 lamps.

A simple diagram of connections should be made, and a brief description of the method of making the tests should be given. From the readings of the instruments the resistance of each branch and the resistance of the entire circuit should be calculated for each case by the application of Ohm's Law.

Discussion. Does increasing the number of lamps in parallel in a circuit increase or decrease the resistance of the circuit?

When the number of equal known resistances are connected in parallel, give a rule for finding the combined resistance.

EXPERIMENT II

THE MEASUREMENT OF THE CURRENT, VOLTAGE, AND POWER OF A MODEL LIGHTING CIRCUIT. TWO-WIRE SYSTEM

This experiment is from Wiley's Loose Leaf Manual.* It is more elaborate but attains the same end as the preceding one.

Apparatus in the Laboratory: Model lighting circuit board; 110-volt direct current.

Apparatus from the Stock Room: Ammeter; voltmeter; yard stick; 15-ampere fuses.

The line wires are No. 14 German silver, 180 ohms per milfoot, to furnish in the limited space of the laboratory conditions similar to those of an actual incandescent lighting circuit in a three-story building. (See Fig. 2.)

All readings of current, voltage, etc., should be recorded on a single outline diagram of the line.

The binding posts at the end of the line are to be regarded as the source of power. Measure the voltage at these terminals and the current in each section of the line *at this voltage.*

Measure the distance from the terminals to the first group of lamps, also the distance from each group to the next succeeding group. (Measure in each case to the point on the mains at which the short leads from the lamps are attached. The resistance of the short copper leads to the lamps may be neglected.)

From its length and mil-foot resistance, compute the resistance of each section of the line. Compute also the " drop " over each section and the voltage at each group of lamps. Check your computed voltage by comparison with the voltmeter readings across the lamps.

Since the voltage may fluctuate, one voltmeter should be kept connected across the supply terminals, and the voltage at the lamps should be read from a second voltmeter when the voltage at the terminals is at the proper value.

* Published by John Wiley & Sons, Inc., New York.

DIAGRAM OF THE MODEL OF A LIGHTING CIRCUIT, USED IN PRATT INSTITUTE, BROOKLYN, N. Y.
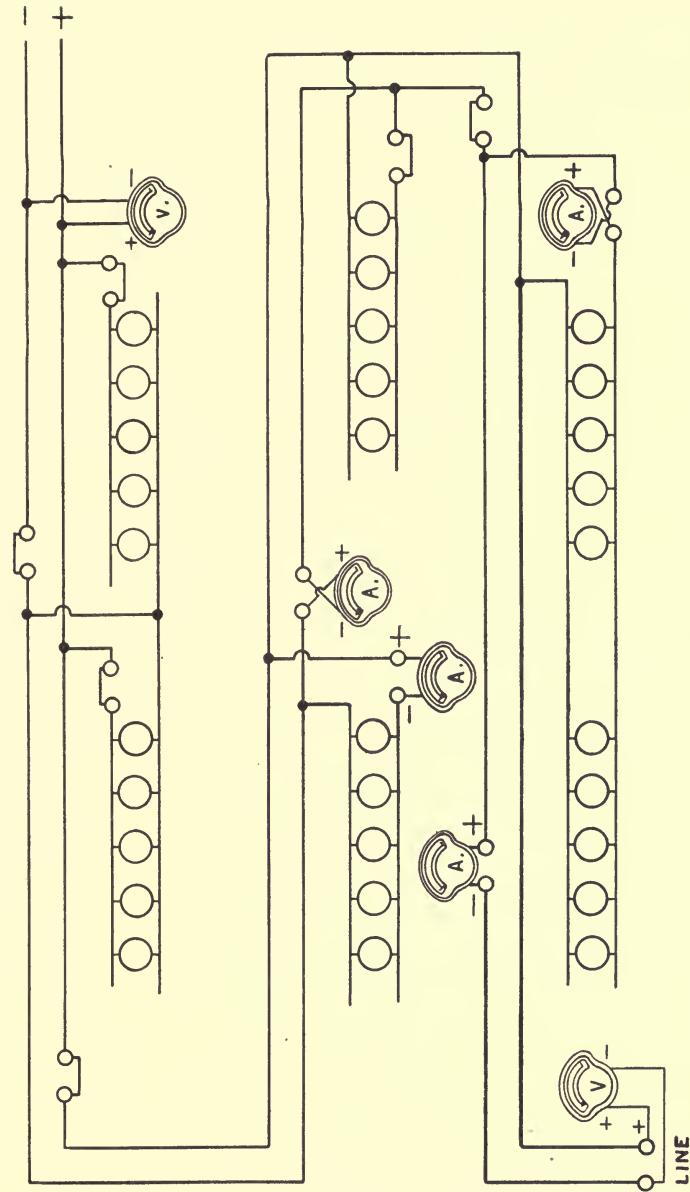
FIG. 2.—The Instruments Shown are Weston Model 267, Voltmeters and Ammeters.

From your data determine also:

1. The watts delivered at the binding post terminals.
2. The watts expended in each section of the feed wire.
3. The watts expended in each group of lamps.
4. The total watts supplied to the lamps and the total line loss.
5. The " efficiency " of the line, i.e., the percentage of the total power supplied which is delivered to the lamps.
6. The resistance of each group of lamps, and the average hot resistance of each lamp.
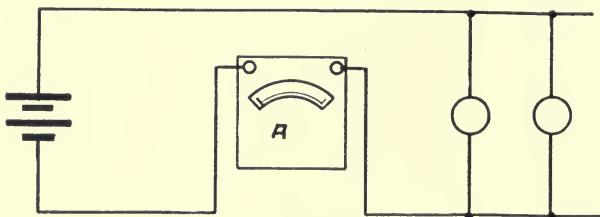
Fig. 3.—Connection for Ammeter with Self-contained Shunt.
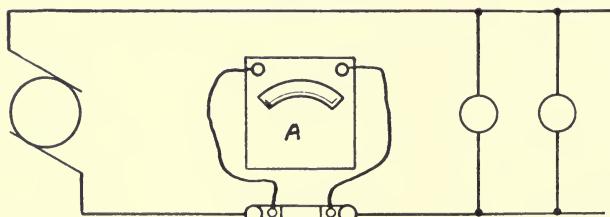
Fig. 4.—Connection for Ammeter with Detachable Shunt.

If conditions permit, we would suggest that a teacher would better have small groups of students use a part of the actual lighting circuit in the school, in place of a model, and follow the directions given in the experiments as far as possible.

This plan is suggested by the letter on page 22 of our Monograph B–1, written by Mr. C. W. Parmenter, Head Master of the Mechanics Arts High School, Boston. The plan is also used by Prof. H. H. Higbie of the Wentworth Institute, Boston, Mass.

CONNECTIONS FOR VOLTMETERS AND AMMETERS

The student's attention should be called to the fact that an ammeter should always be connected in series with the line, whereas a voltmeter should be connected across the line. See Figures 3, 4 and 5.
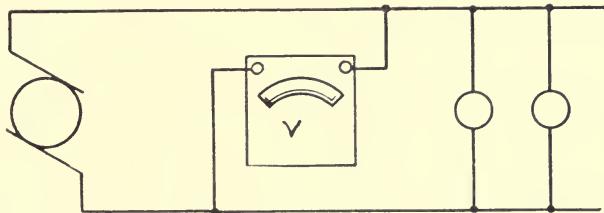
FIG. 5.—Connection for Voltmeter.

EXPERIMENT III

THE FALL OF POTENTIAL ALONG A CONDUCTOR

The nature of a divided circuit and the current in it may have been called the primary idea in the preceding experiments, but they served as well as means of discussing the theory that ·it is *pressure* which actually forces the current through.

Schools have for a long time given an exercise showing the " Fall of Potential along a Conductor," and it merely remains for the teacher to give this exercise a more practical atmosphere to have it continue to be one of the strongest on the list.*

Apparatus Required: Weston ammeter, range 3 amperes; Weston voltmeter, range 3 volts; 1 meter slide wire bridge; storage cell or 2 constant primary cells in series; No. 18 (B. & S. gauge) 40-mil Weston alloy wire; No. 24 (B. &. S gauge) 20-mil Weston alloy wire.

A length of 40-mil alloy wire is stretched over the meter rod and securely clamped. The resistance of 40-mil alloy wire is approximately 0.50 ohm per meter.

One storage cell, with the ammeter in series, is connected with the stretched wire, an extra piece about $\frac{1}{2}$ meter long is included

* See Experiment No. 29, Laboratory Manual in Physics. Wauchope, Scott, Foresman & Co., New York and Chicago.

in the circuit and its length is regulated until the current flowing is 3.00 amperes. See Fig. 6.

The 3-volt range of the voltmeter is also connected as shown and primarily the drop over the entire length of wire is found.

The resistance of 1 meter of wire is then determined by the formula $R = \dfrac{E}{I}$.

It must be borne in mind, however, that this is not a "zero" method, and theoretically, at least, is not correct. That is to
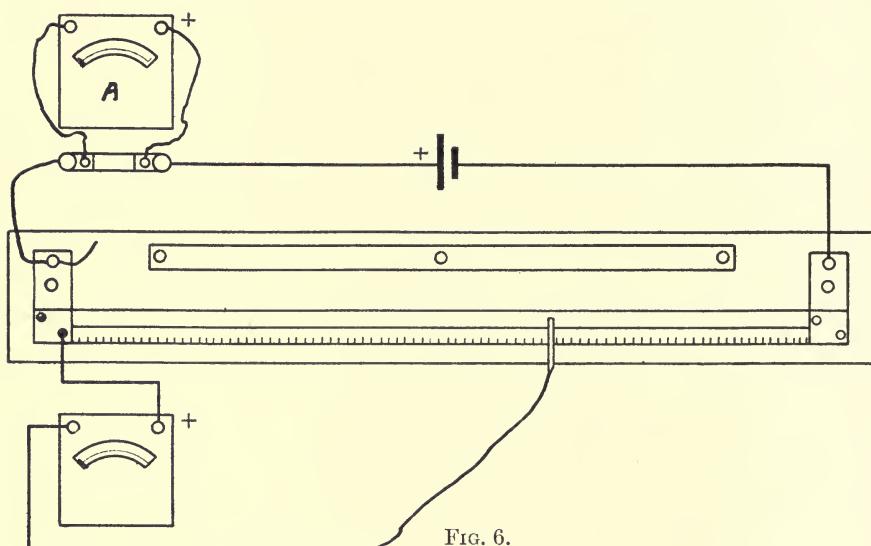
FIG. 6.

say, since current is necessarily flowing through the voltmeter when in use, the instrument therefore forms part of a divided circuit by shunting the resistance wire.

If an improperly constructed voltmeter of low resistance is employed, its introduction will affect the indications of the ammeter by materially reducing the total resistance of the circuit, and its own indications will be erratic and disproportionate when different lengths of the resistance wire are being tested.

Weston voltmeters have sufficiently high resistances to prevent the irregularities referred to, but nevertheless the best method for determining the total resistance of the wire is to ascertain the drop over definite lengths of the wire, such for instance

as 10 centimeters, tabulate the results, obtain a mean value and determine the total resistance by direct proportion.

When sufficient data have been secured relating to the 40-mil wire, a piece of 20-mil is substituted, and the test repeated. A current of about 1.00 ampere may be used. The resistance of 20-mil alloy is about 2 ohms per meter.

A length of copper wire may also be tested, preferably one having a diameter of 0.020 inch, and the relative resistance of copper and Weston alloy wire determined.

Caution: Weston alloy wire has about 23.5 times the resistance of copper wire, and therefore the experimenter must be cautioned to add enough alloy wire to the circuit to compensate for this difference, before the current is completed through the copper wire.

The fall of potential along a conductor may also be beautifully shown with this apparatus by substituting a wire the resistance of which is not uniform. Such a wire may easily be prepared by scraping or filing a resistance wire at irregular distances while stretched, and by coating it with a little solder here and there, afterwards smoothing with emery paper.

The two voltmeter leads are then held, one in each hand, so as to span a section of the wire, and the deflection is noted and compared with the results obtained with other sections of the same length.

EXPERIMENT IV

THE FALL OF POTENTIAL IN A LAMP BANK *

Question. What is meant by " Fall of Potential "?

Apparatus. 110-volt current; three electric lamps; voltmeter.

Directions. Pass the current through the three lamps connected in series as shown in the diagram. It requires electrical pressure to force the current through the lamps. This pressure is measured by the voltmeter. Connect the terminals of the voltmeter to a and d to obtain the volts pressure required to drive the current through all three lamps. In like manner find the difference of electrical pressure between a and c for two lamps, and between a and b for one lamp.

* From "Manual in Physics," by Joseph A. Wauchope.

Results.   Volts pressure required for three lamps =
            Volts pressure required for two lamps   =
            Volts pressure required for one lamp   =

Discussion.   Potential is only another expression for electrical pressure.   Difference of potential means difference of electrical pressure, and fall of potential means fall of electrical pressure. A voltmeter is used to measure the potential difference between any two points in an electrical circuit, just as pressure gauges are used between any two points of a water pipe.   The further away from the pumping station the greater the fall of pressure of the water in pounds per square inch, due to the resistance of the pipes.
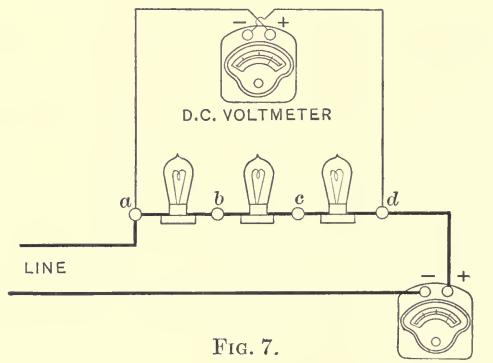

Fig. 7.

So the further the electric current goes in a conductor the greater the fall of potential in volts, due to the electrical resistance of the conductor.   The greater the resistance the greater the fall of potential.   Do the lamps used in this experiment all have the same amount of resistance?   Why do not the lamps give light in this experiment?*

* In the "Physical Laboratory Manual," by Ball, Hauptman and Bateman, issued by the Cooper Union Supply Store, New York, a different method is given, which consists in employing a lamp bank, a gold-leaf electroscope, and a Weston voltmeter.

They call attention to the fact that the leaves of the electroscope will diverge less and less as the knob of the electroscope is connected at the points of decreasing potential, and then add:

"Now use a Weston voltmeter in place of the electroscope and note the readings of the voltmeter for the same points.   Note how much more accurately the potential difference can be estimated by means of the voltmeter than by means of the electroscope.

EXPERIMENT V

NUMBER OF WATTS FOR ONE BRITISH THERMAL UNIT PER SECOND

In " Physics," by Mann and Twiss,* the following exercise is suggested, which has long been successfully used in schools to teach that the electrical energy delivered to an incandescent light is transformed into heat energy.

An ordinary 16-candle-power, 110-volt, electric lamp is placed in a jar containing a measured amount of water and a thermometer (Fig. 8). The heat from the lamp warms the water. If the jar contains 2 pounds (1 quart)

Fig. 8.

of water and if a Fahrenheit thermometer is used, the temperature of the water rises about $1\frac{1}{2}°$ F. per minute—i.e., the water is heated at the rate of 3 B.T.U. a minute.

Fig. 9.

A voltmeter V and an ammeter A measure the electric power supplied to the lamp. If the voltmeter reads 110 volts, and the ammeter reads $\frac{1}{2}$ ampere, the power supplied is 110 (volts) $\times \frac{1}{2}$ (ampere) $= 55$ watts. Hence, roughly, 55 watts $= 3$ B.T.U. per minute; or 1100 watts $= 1$ B.T.U. per second.
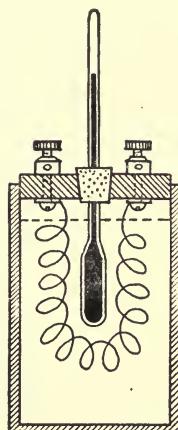
The first determination of this relation was made more accurately by the same Joule who made the first determination of the relation between the B.T.U. and the foot-pound. The apparatus (Fig. 9) does not differ in principle from that used by Joule. A coil of platinum wire is placed in a jar containing a measured quantity of water and a thermometer. A
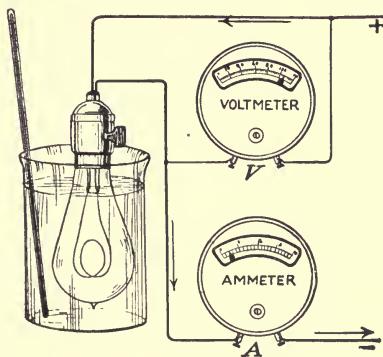
* Scott, Foresman & Co., Publishers, New York and Chicago.

voltmeter V and an ammeter A, arranged as shown in Fig. 7, measure the number of watts of electric power used in heating the coil. The number of B.T.U. given up by the coil to the water in a certain time is obtained by multiplying the number of pounds of water in the jar by the number of degrees F. rise in temperature.

Joule's experiments have been repeated many times by many other scientists, using different current strengths and different kinds of coils. The results of all of these experiments show that there is a constant ratio between the heat unit and the unit of electric power; and they give the accurate value of this ratio as

$$1055 \text{ watts} = 1 \text{ B.T.U. per second.}$$
$$4.2 \text{ watts} = 1 \text{ gram-calorie per second.}$$

The above exercise, as described, deals merely with the relation that the power units (watts and B.T.U. per second) bear to each other.

EXPERIMENT VI

HEATING OF AN ELECTRIC CURRENT

The following directions, reprinted from "Laboratory Exercises in Physics," by Fuller and Brownlee, seem to be more practical than the preceding one.*

Object. To measure the number of calories of heat furnished by an incandescent lamp and to calculate the cost.

Apparatus: Calorimeter; thermometer; 16-candle-power incandescent lamp; porcelain keyless socket; voltmeter; ammeter; source of 110-volt current; graduate, or balance and weights; flexible insulated wire for connections; watch or clock with second hand.

By allowing a lamp to heat a known weight of water for a measured time, we may find the calories per second furnished by the lamp. If we know the current and voltage of the lamp, we may estimate the heat liberated per kilowatt-hour. Although *all the heat* liberated by the lamp will not be measured in this

* See also Experiment 92 in "Experimental Physics," by Smith, Tower and Furton. Ginn & Co.

experiment, yet the efficiency of the lamp as a heater, as used here, compares favorably with regular heating appratus.

Experimental. A porcelain keyless socket is connected to a 110-volt line with an ammeter between the socket and the 110-volt terminals (Fig. 10). A voltmeter is connected across the terminals of the socket. A lamp is then screwed into the socket and the switch closed in the circuit to make sure that the connections are correct and that the instruments read in the proper direction. The lamp is then turned off till needed.

Into a nickel-plated brass calorimeter is placed 250 grams of water at a temperature six or seven degrees below room temperature.
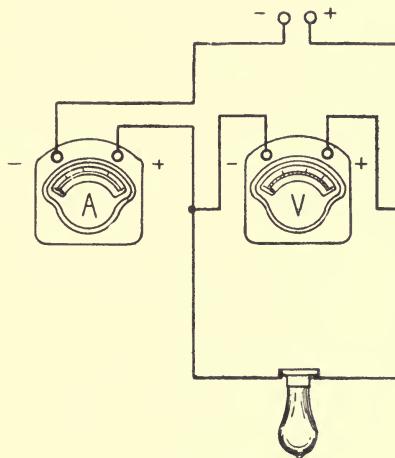
Fig. 10.

This is stirred thoroughly with a thermometer and the temperature noted; immediately the current is turned on through the lamp, which is inserted in the calorimeter, the exact time in minutes and seconds being noted.

The time and the temperature of the water are recorded in the tabular form near the top of the left-hand page, the voltmeter and ammeter also being noted and recorded. The lamp should be immersed until the tip rests on the bottom of the calorimeter, and the thermometer should stand in the calorimeter beside the lamp. For the next five minutes the lamp

burns inverted in the water. By moving the lamp up and down in the water, never raising it more than a quarter of an inch from the bottom, the water can be kept stirred and so of equal temperature throughout.

The calorimeter should not be handled during the experiment. The voltmeter and ammeter should be frequently observed, and if there is any variation, the average reading for the whole time should be the one recorded and used.

When the lamp has been in the water exactly five minutes, take it out promptly, stir the water vigorously with the thermometer, and read and record the temperature.

Using fresh quantities of water, repeat the test twice. The water equivalent of the calorimeter should be obtained from the instructor.

Make a sectional drawing of the calorimeter with lamp and thermometer in place and with the connections of the instrument shown.

A brief description of the method of the experiment should accompany the drawing.

From the weight of the water, with the water equivalent of the calorimeter added, and the change of temperature, the number of calories furnished in five minutes can be calculated. The number of watt-seconds is found by multiplying volts, amperes, and seconds together. From these two results calculate the calories per watt-second and per kilowatt-hour. As the time and the weight of water are the same in all three tests, the averages of temperature changes, volts, and amperes will be used in the calculation. The problem called for in the conclusion should be worked out in the note-book, using the local rate for electricity.

CALCULATED RESULTS

Corrected weight of water (water + water equivalent of calorimeter)....   g.
Average temperature change in five minutes.......................   c.
Calories furnished in five minutes...................................   cal.
Calories furnished per second....................................   cal.
Watt-seconds of energy used in five minutes.......................   w. s.
Calories per watt-second...
Calories per kilowatt-hour...
Cost of current per kilowatt hour..................................   c.

Discussion.   Explain any way in which heat generated by the lamp may escape without being measured in this experiment.

Conclusion.   At the price of . . . ¢ per kilowatt-hour, the cost of raising 4 liters of water from 15 to 100° C. will be . . . ¢ if an electric heater of the same efficiency as the lamp is employed.

POWER

A series of exercises designed to emphasize the difference between work and power as measured in electrical units (e. g., watt-hour and kilowatt) is commercially of primary importance.

In " A High School Course in Physics," by Gorton,* will be found the following terse and lucid definition:

" POWER OF AN ELECTRIC CURRENT.   Since *power* refers to the rate at which work is done or energy expended, it may be found by simply dividing the total energy expended by the time. In an electric circuit, therefore, the power is measured by the product of the potential difference and the current strength; or, *Power* (watts) = volts × amperes."

EXPERIMENT VII

EFFICIENCY TEST OF AN ELECTRIC MOTOR

There is a rapid increase in the number of school laboratories which have a small electric motor.   These motors are usually of recent design, and of $\frac{1}{2}$ horse-power or over in rating.

The student who uses motors of this type is usually impressed by the fact that he is working with real commercial quantities of energy and with actual life-size machines.

A determination of the brake horse-power and efficiency of such a motor is considered an essential part of the laboratory course in many of our high schools.   Such a test is very well described in " Physics," by Mann and Twiss, as follows:

" As with simple machines, water motors, and steam engines, the most important thing about electric machines is the efficiency.

" Suppose that we have bought a 110-volt motor that is built to develop two horse-power, and we wish to test its power and efficiency in order to see whether it does what is claimed for it.

* D. Appleton & Company, Publishers.   New York and Chicago.

The voltmeter V, whose terminals are attached to those of the motor (Fig. 11), measures the $D P$ at the motor. It should read 110 volts. The ammeter A, placed in the power circuit in series with the machine, measures the number of amperes flowing through the motor. Suppose it reads 16 amperes. Then the power supplied to the motor (power in) is

$$110 \text{ (volts)} \times 16 \text{ (amperes)} = 1760 \text{ watts.}$$

" A brake is applied to the axle of the motor and the readings made.
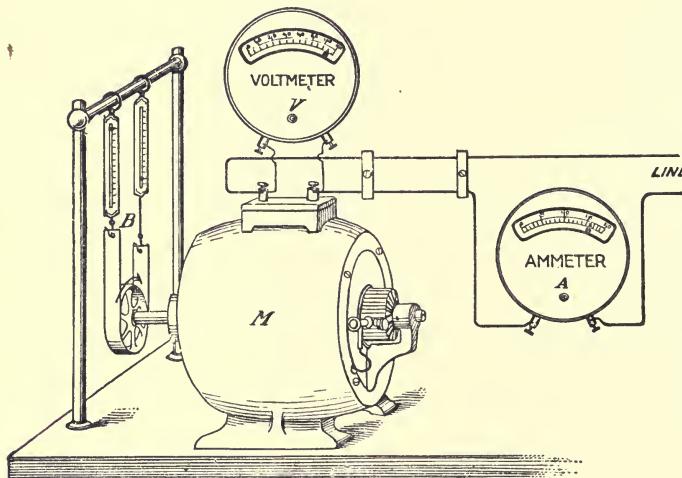
Fig. 11.

" Let us suppose these readings to be as follows:
" Circumference of brake wheel, 2 feet; revolutions per minute, 360; pull on brake, 82.5 pounds. Then the power obtained from the motor is:

$$82.5 \text{(lbs.)} \times 2 \text{(ft.)} \times 360 \text{(r.p.m.)} = 59,400 \text{ ft.-lbs. per min.}$$

" Dividing this by 33,000 ft.-lbs. per min. to reduce it to horse-power, we get 1.8 horse-power.
" So 1760 watts of electric power was supplied to the motor to make it do work at the rate of 1.8 horse-power. This result enables us to compare the efficiency of this motor with that of

others; but it does not state what the real efficiency of this motor is, because the power in is expressed in watts, and the power out is expressed in horse-power."*

RESISTANCE

The most accessible means for measuring quantities with commercial accuracy are the ones most frequently ignored. In the measurement of resistance it is perhaps true that instructors neglect the voltmeter-ammeter method because it seems so obvious. Certainly no quicker method could be selected than that of placing an ammeter in series, and then connecting a voltmeter across the terminals of the conductor to be tested. Nothing else is necessary except perhaps a rheostat to regulate the amount of current.

Every student knows enough of algebra and of Ohm's law to solve for the resistance when he has taken such measurements. The student who is thus early asked to test the resistance of each phase of an induction motor, the fields of a direct-current motor, the ballast coils in an arc lamp, or any other electrical device, starts with a fair appreciation of what ordinary commercial measurements of resistance are like.

The following experiment fully describes the advantages and limitations of this method:

EXPERIMENT VIII

THE DETERMINATION OF LOW RESISTANCES BY THE AMMETER AND VOLTMETER METHOD

Apparatus Required: Weston ammeter; Weston millivolt-meter, 500 millivolt range; Weston voltmeter, 3 and 15 volts; unknown low resistance; storage battery, 3 cells; Weston alloy or carbon rheostat.

This method is identical in principle with the one by which the fall of potential along a conductor is determined. Commercially, it is constantly used for testing the resistances of bus-bars, dynamo armatures, shunts, etc.

* See also Experiment 37, Wauchope's Manual in Physics. Scott, Foresman & Co. New York and Chicago.

A Weston ammeter, preferably with a detachable shunt having a standard drop, is connected in series with the resistance material to be measured, a rheostat, and a source of steady current.

Current is regulated until a suitable ammeter deflection is obtained.

If the resistance of the material to be tested cannot be determined approximately by calculation, a voltmeter should first be connected across its extremes a and b (see Fig. 12) and a pre-
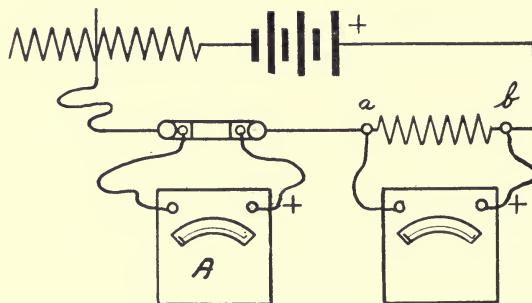

Fig. 12.

liminary test made to learn whether the potential between these points is too great to permit the use of the millivoltmeter. If this is not the case, the millivoltmeter is substituted, its deflection noted, and the resistance between a and b is found by the formula

$$X = \frac{E}{I}$$

I being the current and E the e.m.f. indicated by the millivoltmeter.

Strictly, the value obtained is not that of the resistance material only, but of the combined resistance of the material and the millivoltmeter in parallel.

To determine the resistance accurately, a more refined method must be used.

A variation of the above method, which is useful for measuring armature resistance, etc., results from the use of a single millivoltmeter, and a known low resistor approximately equal

to the unknown resistance, in place of the shunt.   Then by first connecting the millivoltmeter across the resistor, the current through the circuit may be computed by Ohm's law.   Next, by placing the instrument terminals across the unknown resistance, the fall of potential through it and also its resistance may be then determined.   With steady current, this method is as accurate as the preceding one, but since it is assumed that the conditions do not change between tests, it cannot be relied upon with fluctuating current.

INSULATION

An ideal condition of affairs would be to have a perfect conductor of electricity protected by a perfect insulator.   We would then always secure 100 per cent efficiency, irrespective of the length of cross-section of our conductor.   But unfortunately we have neither, since all conductors have resistance and all insulators are imperfect conductors.   The result is that there is always a current discharge on a line.   This discharge or " leakage " is increased by the use of poor or worn insulating material and by dampness.

In all electric light and power stations, leakage is regarded as waste, involving a direct financial loss.   Therefore. it is of great importance to be able to " keep up the line insulation " and to understand how to locate leaks or " grounds."

EXPERIMENT IX

THE DETERMINATION OF HIGH RESISTANCES BY THE VOLTMETER DEFLECTION METHOD

Apparatus Required: Weston direct-current voltmeter, 150-volt range; high unknown resistance; direct-current line voltage, 100 to 120 volts.

On a direct-current line, in order to successfully determine insulation resistance, it is necessary to use a Weston permanent magnet movable-coil type of high resistance voltmeter, with a uniformly divided scale.   The resistance of the instrument should be known.

The normal voltage of the line is then found by connecting the voltmeter across the line, as shown in Fig. 13, and the deflection noted.
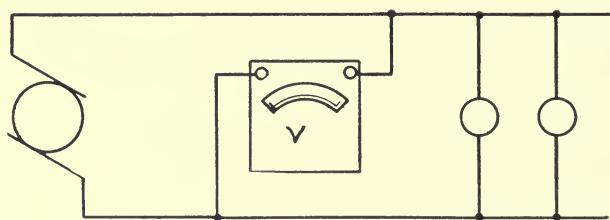

FIG. 13.

One binding post of the instrument is then grounded by connecting it with any convenient water, gas or steam pipe, and the other binding post connected directly with one of the generator terminals. The other generator terminal is connected with the line to be tested and the resultant deflection also noted. See Fig. 14.
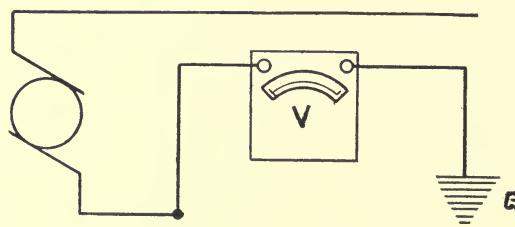

FIG. 14.

The resistance of the line (in ohms) is then found by the formula:

$$X = \frac{S \times R}{S'} - R.$$

S = First deflection in scale divisions;
S' = Second deflection in scale divisions;
R = Instrument resistance.

Example:

$$S = 120; \qquad S' = 20; \qquad R = 15000;$$

$$X = \frac{120 \times 15000}{20} - 15000;$$

$$X = 75000.$$

The insulation resistance of a line or cable may readily be determined in this manner if it is not too high.

Sometimes, when the insulation is very poor, a fine classroom illustration can be made by grounding the line through an ammeter in series with an incandescent lamp, as shown on Fig. 15.
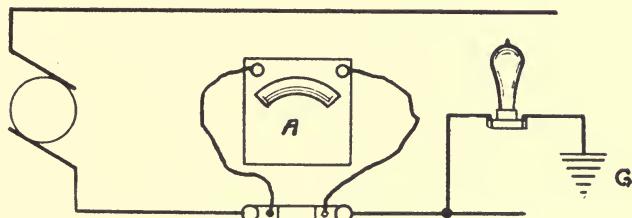

Fig. 15.

EXPERIMENT X

THE WHEATSTONE BRIDGE

The Wheatstone bridge remains the time-honored instrument for the highly accurate determination of resistance. In commercial testing laboratories, it is regularly used for routine and special work, demanding greater precision than can readily be obtained by more rapid methods. Its use is also common for measurements in which the large currents or voltages required by other methods are either unobtainable or objectionable. As an illustration, reference might be made to its use in telegraph and telephone tests for faults and grounds. The Wheatstone bridge is operated by specially trained workers, and for educational purposes it should not be classed with voltmeters, ammeters, and wattmeters as an instrument with which every high-school graduate should be familiar.

Many teachers question the wisdom of attempting to teach
beginners the principle and operation of this instrument, as much
because of the indifferent success which so frequently results as
because of its special character.   This discussion is intended for
those teachers who feel that they must attempt its use.   The
slide-wire form is here suggested, not only because it is already
in common use, but also because it lends itself to a close corre-
lation between the " Fall of Potential " exercises which should
precede it.

Apparatus Required: Slide wire bridge;   Weston student
galvanometer;   Weston ammeter;   resistance box;   resistance
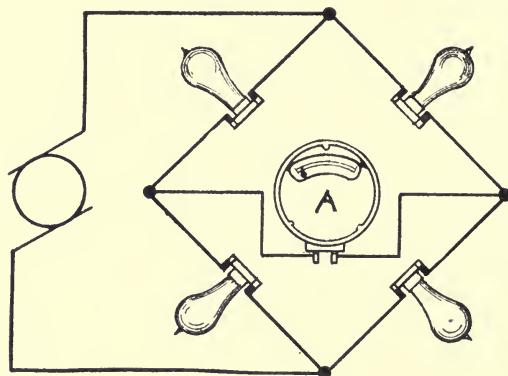
Fig. 16.

wire; coil of unknown resistance; one or two cells; incandescent
lamps.

If four incandescent lamps are arranged in multiple series,
as shown in Fig. 16, and connected with the line, they will serve
excellently to demonstrate the principle of the parallelogram
of forces, as exemplified by the Wheatstone bridge.   Even if
the rest of the exercise is omitted, this part should be given as a
class-room demonstration.   The instrument should preferably
be a zero center ammeter.

Suitable questions would be as follows:

If an ammeter is connected (as shown), what will happen?

Will it indicate, and if not, why not?

If one of the lamps is removed, what will be the result?

If a lamp of different size (resistance) is substituted, will it make any difference?

If, instead of the lamps, a parallelogram of resistance wire is constructed so that the four sides have the same resistance, and a battery and galvanometer are connected, as shown in Fig. 17, the current will split where A and B unite, pass through A and X and also through B and R, reuniting where R and X join. The four " arms " of the bridge being alike, no current will flow through the galvanometer when connected as shown. In other words, the potential at the junction of AX and BR
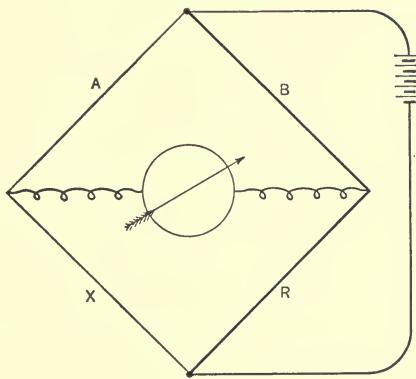

Fig. 17.

will be the same. The battery and galvanometer may then be interchanged without affecting the balance.

To construct a practical bridge, it is only necessary to substitute for A, B, X, and R conductors of large area and negligible resistance with suitable gaps for the insertion of resistance coils and the material to be measured. See Fig. 18. If then, A and B are each 100 ohms and R is also 100 ohms, a balance is secured by adjusting X, and when no current flows through the galvanometer the resistance of X will be 100 ohms. If the resistance of X is to be determined, R is made adjustable and is varied until it equals X. The resistance of R and X, if equal to each other, may differ greatly from A and B, and an equilibrium be established, provided A and B equal each other. Finally, A, B, R, and X may all differ in resistance and a balance be

secured, provided a proportionality exists in their respective resistances—for instance, when

$$A = 10, \quad B = 100, \quad X = 35 \quad \text{and} \quad R = 350.$$

These conditions obtain when an uneven bridge or ratio is used in making measurements.
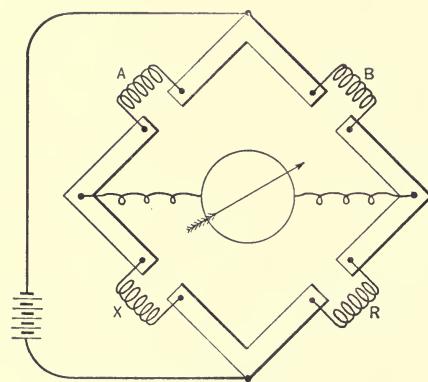
FIG. 18.

EXPERIMENT XI

THE SLIDE WIRE BRIDGE

In the slide-wire form of bridge A and B consist of a single wire of uniform resistance. Contact may be made at any point on this wire, and a scale is provided to determine the position of contact. See Fig. 19. The galvanometer is preferably connected as shown, an unknown resistance is inserted at X and a box of coils at R. The slide-wire contact is at first placed centrally, and an approximate balance secured by varying R. A place is then found on the slide wire where perfect balance is secured.

Since the scale is divided into a thousand parts, the resistance of X can be closely determined by simple proportion.

EXPERIMENT XII

THE EFFECT OF TEMPERATURE ON THE RESISTANCE OF A LAMP FILAMENT *

Apparatus: 110-volt direct current; series lamp resistance or any suitable adjustable resistance; switch with 6-ampere fuses; ammeter; voltmeter; lamps to be tested. (These should be of several types.)

The difference between the resistance of an incandescent lamp filament when the switch to power is first closed and the resistance
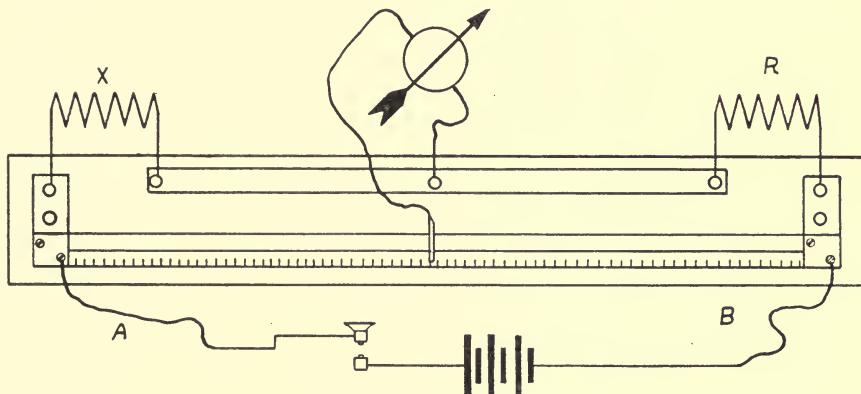

Fig. 19.

of the same filament an instant later when the filament has been raised to its normal operating temperature, is a matter of considerable commercial importance. With the old type carbon filaments, where the temperature effect is to give a smaller initial current, the phenomenon could be safely allowed to adjust itself. With the newer metallic filament lamps in which the first rush of current may be much greater than the normal operating current, some protection to the line, when the power switch is first closed, is frequently necessary where large groups of lamps are being supplied. The character and extent of this temperature

* From "The Loose Leaf Laboratory Manual," published by John Wiley & Sons, Inc.

effect varies with various types of lamp filaments will be apparent from the following study.

Method. Connect your apparatus with the 110-volt circuit as shown in the diagram, using first a carbon filament test lamp. (The voltmeter is here connected around the ammeter so that the latter may read the true current through the lamp.)   Put a fuse in the line to protect the ammeter.   See Fig. 20.

Data and Results. Take readings of both the ammeter and voltmeter with all the lamps in the lamp board in series with the test lamp.   Then cut out one lamp at a time, and take readings of the voltmeter and the ammeter for each step,   until the last

**EFFECT OF TEMPERATURE ON THE RESISTANCE OF AN INCANDESCENT LAMP**
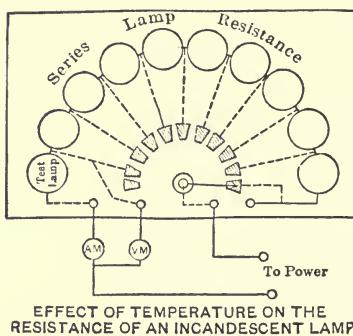
Fig. 20.

reading is for the test lamp alone.   *The ammeter and the voltmeter should be read simultaneously.*

Compute the resistance of the test lamp for each current.

You have no actual measurement of temperature here, but as the current increases the temperature of course rises—very perceptibly for the last two or three readings.

Plot a curve from your data, using the resistances of the lamp as ordinates, the current as abscissae.

What conclusion may be drawn regarding the effect of increase of temperature on the resistance of the filament?

Test in the same way lamps having a treated carbon filament and lamps having a metal filament as in the tantalum and tungsten lamps.   Plot curves for each and compare the filaments as to their change in resistance with rise in temperature.

Addenda. Connect the voltmeter across the test lamp only, and note the ammeter reading. Compare this with the ammeter reading taken with the voltmeter connected across both the lamp and ammeter. Which ammeter reading gives the true current through the lamp, and why? Which voltmeter reading gives the true voltage across the lamp, and why? When would it be best to connect the voltmeter across both the ammeter and test piece? When across the test piece only?

Give detailed reasons for your answer. (See " Elements of Electricity," p. 413.)

PROBLEMS: 1. Measure on a Wheatstone bridge the resistance of the tungsten filament lamp at room temperature (20° C.). Using the temperature coefficient of tungsten as .0051, and the resistance found for the lamp in the above experiment when on its rated voltage, compute the temperature of the filament when used on its rated voltage.

2. In an experiment like the above the voltmeter was connected across the test lamp only. If the resistance of the voltmeter is 16,500 ohms, the voltmeter reading is 110 volts, and the ammeter reading is .285 amp., what is the true current through the lamp filament?

THE WESTON DIRECT-CURRENT AMMETER

For pedagogic purposes the Weston ammeter with detachable shunts has marked advantages over the instrument with a self-contained shunt. The instructor may call attention to the fact that a " shunt " is really a part of the main conductor carrying the current and that only a small fraction of the total current passes through the movable system of the instrument.

A clear conception of the operation of a Weston ammeter may be obtained by means of a water-main analogy. The water main or trunk A through which water is flowing under pressure as in city water mains (Fig. 21), may be fitly compared with the conductor or bus-bar F (Fig. 22). The section B of reduced diameter corresponds with the shunt E, and the small pipes C may be compared with the leads G. It is obvious that, since the pipes C are of smaller dimensions than B, less water will flow through them; and, provided that the proportion between B and C is fixed and constant, the quantity of water flowing through the meter D will depend upon the total quantity flowing through B, and hence D may be calibrated to indicate the total

flow of water instead of merely indicating the quantity passing through *C*.

On the same principle the scale of the instrument *H* may be figured to indicate any required amperage; but, although the
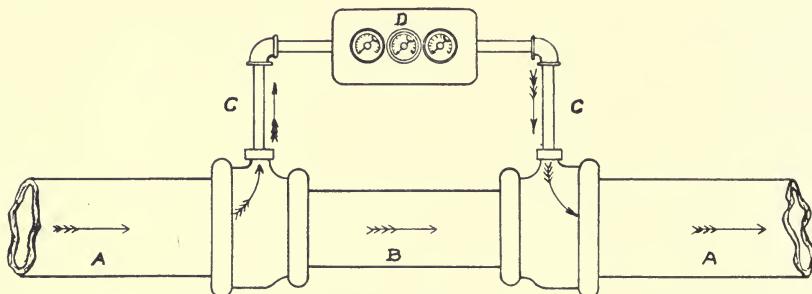

FIG. 21.

total current flowing through *F* may be 20,000 amperes or more, the sensitivity of the movement of *H* to current is so great that only about 3/100 ampere is required to produce a full scale deflection, and under proper conditions no current in excess of
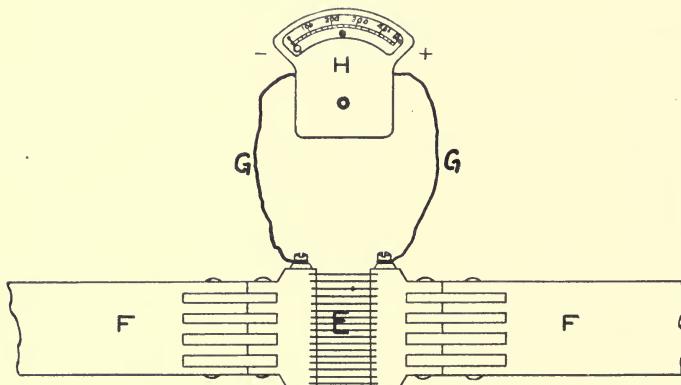

FIG. 22.

this amount will ever pass through *H*. The conductors *G*, together with the movable coil and resistors inside of *H*, are so proportioned that the flow of current through *H* is limited to the proper amount. But, nevertheless, instead of merely indicating

the amount of current passing through its movement, H may be calibrated to correctly indicate the total current flowing through FEF.

Finally, the quantity of current which will flow through G will depend upon the resistance of the shunt E; therefore, since shunts of different resistance and current capacity may be used in place of E, the instrument H may be used for an unlimited number of ampere ranges.*

EXPERIMENT XIII

THE STUDY OF AN AMMETER †

Apparatus: Ammeters of several types.

Ammeters may be divided into two classes: (1) Thermal—in which the movement of the index is secured through the change in length of a wire when heated by the current passed through it. The heat generated, and therefore the change in length, is here proportional to the square of the current; and

(2) Electromagnetic—in which the motion is due to the magnetic field produced when current is sent through the coils or coil of the instrument. Electromagnetic ammeters may be of three types: (*a*) Solenoidal; (*b*) permanent magnet; (*c*) electrodynamometer.

Data and Results. Examine instruments of several of the above types and report upon the following features for each:

1. The type of instrument.
2. The scale: range and graduation. Divisions—uniform or varying width. Why?

---

*A shunt in electrical parlance was formerly defined as a resistor connected in multiple with an indicating instrument carrying the main current to reduce the current flowing through the latter; but, since the introduction of Weston instruments, "shunt" has become the trade name for a constant resistor of special form, having dimensions which will permit its practical use in series with a conductor carrying a current, independent of the current capacity of its indicating instrument.

† From " The Loose Leaf Laboratory Manual." John Wiley & Sons, Inc.

3. The construction:
    (*a*) Fixed parts; nature, material, construction and arrangement.
    (*b*) Moving parts; construction, bearings; control by which they are returned to zero; damping.
    (*c*) Shunt.
4. The connections by which the current enters and leaves the instrument. The circuit from bind post to bind post.
5. The resistance of each coil and of each shunt separately. The resistance of the instrument from terminal to terminal.

Explain the construction and arrangement of each essential part by simple diagrams, and show by a simple diagram how the parts are assembled in the complete instrument. Show the direction of current through each instrument and explain the reason for the deflection of the moving parts by the current. State in each case whether the instrument is suited for the measurement of direct or alternating current and why.

If the instrument is suited for both direct and alternating current, will the same calibration do for both kinds of power? Explain the reason for your answer.

By means of a millivoltmeter measure the millivolt drop across each instrument on full scale reading and compare this with the computed value. Account for any difference.

Show by diagrams the proper directions of the instrument to a line to measure the current taken by a motor.

PROBLEMS. The full scale reading of a millivoltmeter is 100 millivolts. The resistance of the moving coil is 5 ohms.

(*a*) What resistance must a shunt be in order to be used with this millivoltmeter to have the scale read amperes?

(*b*) What must the resistance of a shunt be in order that the full scale reading may indicate 10 amperes?

SUGGESTIONS FOR FURTHER STUDY

If the "drop" of a Weston station shunt of specified ampere capacity is 50 millivolts, what will its resistance be between its potential terminals?

Detach the shunt of a Weston ammeter with removable shunts, and measure the resistance of the instrument by means of a bridge.

Note: Minimum current should be used, and the battery key kept depressed to prevent the disturbing effect of currents induced by the motion of the movable coil.

If the drop of a shunt is 50 millivolts, the instrument for which it is intended must necessarily give a full scale deflection with 50 millivolts. What then will be the amount of current required to give a full scale deflection when the instrument is used without a shunt?

Explain what the effect would be if the leads from the shunt to the instrument were altered in length or resistance.

Determine the power (in watts) consumed by the instrument with shunt when in circuit with full scale deflection.

THE WESTON DIRECT-CURRENT VOLTMETER

The Weston direct-current movable coil voltmeter consists essentially of a light rectangular coil of copper wire usually wound upon an aluminum frame, pivoted in jeweled bearings and mounted to rotate in an annular space between the soft iron core and the specially formed pole pieces of a permanent magnet. A light tubular pointer is rigidly attached to the coil and moves over a calibrated scale.

The current is led into and from the coil by means of two spiral springs, which serve also to control its movement. This movement is due to the dynamic action between the current flowing through the coil and the magnetic field of the permanent magnet. (See Fig. 23.) The pointer becomes stationary and the coil attains a position of equilibrium when the opposing forces of the springs equal the force caused by the rotary tendency of the coil. Since the magnetic field is uniform and the torsion of the springs proportional to the deflection, the scale divisions are practically uniform.

The well-known aperiodic or " dead-beat " quality of Weston instruments is produced in this type by foucault currents generated in the aluminum frame when rotating through the magnetic field. These Foucault currents have a sufficient influence

on the movement of the coil to cause it to come to rest almost instantly and without friction.

Ball, Hauptman and Bateman, when dealing with the subject of Potential Differences,* make the following statement, which we quote not only because it is well expressed, but also since it serves excellently to describe the proper conditions under which voltmeters may be uesd:

" It has already been stated and shown in the previous experiments that, when certain electrical generators are employed, the P.D.'s between bodies charged from such generators may remain unchanged even when these bodies are connected by a conductor. This effect may, under proper conditions, be made the basis of measurement of P.D. The instruments generally employed for the commercial measurement of P.D. are based upon this principle. It must be noted, however, that the use of such instruments is admissible only when the current which passes through them does not alter the P.D. between the points to which they are connected."

If, therefore, an instrument is used to measure this P.D., it should, to perform its functions properly, be so constructed that it is extremely sensitive to current.

Weston voltmeters fulfill these conditions. It is true that they are conductors and require a small current to render them operative, and that there are conditions under which they would not indicate correctly. For instance, they could not be used with marked success to determine the static charge of a Holtz machine or a Leyden jar. Neither would they correctly indicate the potential of a Zamboni dry pile,† nor should they be used to directly test the e.m.f. of a Weston standard cell.

But since Weston voltmeters require only about 1/100 ampere with full scale deflection, there will be no appreciable fall in potential when they are connected across any commercial source of current, ranging from a light and power plant to a dry cell.

An exercise similar to the following one, on the " Study of a Voltmeter," should in our opinion form part of every laboratory course in physics.

* Experiment No. 107, Laboratory Experiments, 1913.
† Deschanel's Natural Philosophy, 1870.

EXPERIMENT XIV

THE STUDY OF A VOLTMETER*

Apparatus Required: Voltmeters of several types.

Voltmeters may be of the types suggested in preceding experiment, or may be electrostatic.

Examine instruments of several types and report upon the following for each:

1. The type of instrument.
2. The scale: range and graduation. Divisions—uniform or varying width. Why?
3. The construction:
    (*a*) Fixed parts: nature, material, construction and arrangement.
    (*b*) Moving parts: construction; bearings; control by which returned to zero; damping.
    (*c*) Series coils. Double-scale instruments.
4. The connections by which current enters and leaves the instrument. The circuit from binding post to binding post.
5. The resistance of the instrument. Resistance per volt.

Explain the construction and arrangement of each essential part by a separate diagram, and show by a simple diagram how the parts are assembled in the complete instrument. Show the direction of current through the instrument in each and give the reason for the deflection of the movable parts. Why does the reading indicate the difference of potential at the terminals? State in each case whether the instrument is suited to the measurement of direct or alternating voltages and why.†

* From " Physical Laboratory Notes," by J. M. Jameson.
† See also "Electrical Instruments and Testing," (Chapter IV), by Schneider and Hargrave, published by Spon & Chamberlain, N. Y., also "Lessons in Practical Electricity," Lesson XVIII, Swoope, published by D. Van Nostrand Co., N. Y.

Suggestions for Further Study. Note or measure the resistance of one or more ranges of a Weston voltmeter of the movable coil type.

Determine the current actually flowing through the instrument with full scale deflection.

Determine the power (in watts) required to produce a full scale deflection with different ranges.


To Lower Spring   To Upper Spring
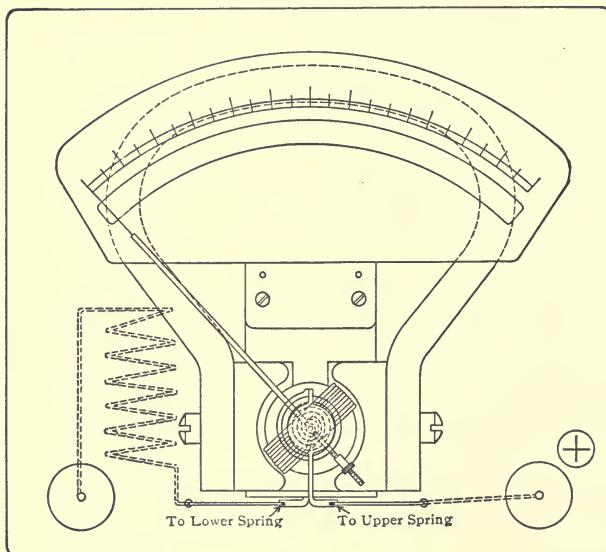
FIG. 23.

Explain why a voltmeter the resistance of which is high (in ohms per volt) is preferable to one of low resistance.

Explain the construction of a Weston " soft-iron " movement and field.

EXPERIMENT XV

THE ACTION OF A SIMPLE CELL

Since generators and storage cells have taken the place of the primary batteries once largely used for the commercial production of current, the exercise which follows may be rated by many instructors as too abstract to deserve a place in a practical physics

course. However, nearly every modern text book still retains
it, and it remains for the instructor to decide whether it suffices
to merely refer to Volta's discoveries, or emphasize their signifi-
cance by means of an exercise which enables the student to pro-
duce current by chemical action.

Apparatus Required: Low range, direct-current, 5-ampere
Weston ammeter; low range, direct-current, 1.5- or 3-volt Weston
voltmeter; strips of sheet zinc, 2×6 inches; strips of sheet
copper, 2×6 inches; glass jar, about 5 inches in diameter and 4
inches deep; ten per cent sulphuric acid solution; mercury;
copper wire.
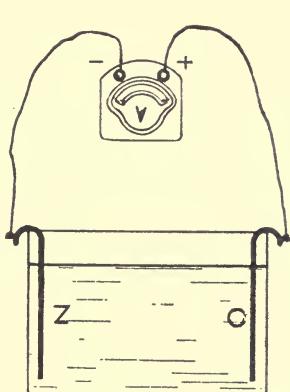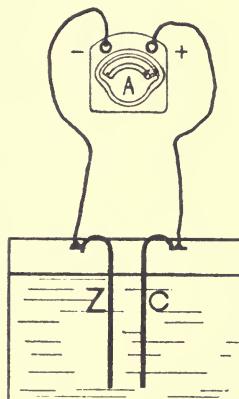
Fig. 24.   Fig. 25.

Copper leads are to be soldered to the plates, the latter being
bent so that they may hang in the solution from the edge of the
jar.

The voltmeter is first connected and deflection noted, which
will be about 1 volt. See Fig. 24.

The ammeter is then substituted and deflection also noted.
Current when circuit is first completed will be about 1 ampere;
but since polarization rapidly sets in, the current at once decreases.
Why?

Note the large number of hydrogen bubbles passing to the
surface of the liquid from the zinc plate. Why?

Substitute an amalgamated zinc plate. Note that no hydro-

gen forms except when the circuit is closed, and that the current is comparatively constant.   Why?

With the ammeter in circuit, decrease the distance between the zinc and copper poles, and note the increase in current.   Why? See Fig. 25.

Disconnect the ammeter and try the above experiment with the voltmeter.   Note that there is no appreciable difference in the e.m.f.   Why?

With the plates hanging from the edge, connect both instruments successively, and note their deflections.   Determine the resistance of the circuit (cell, ammeter and leads) by the formula

$$R = \frac{E}{I}.$$

R = resistance of circuit; E = e.m.f.; I = current.

When both instruments are connected at the same time, the indicated e.m.f. of the voltmeter is much less than it is when the ammeter is not in parallel.   Why?

NOTE.   In making the above experiments the student may be permitted to connect the ammeter as stated, because the resistance of the cell is sufficiently high to limit the flow of current to a safe amount.   He should, however, be cautioned about using an ammeter in this manner when the resistance of a cell is likely to be low, and consequently its current is large.   For instance, an ordinary dry cell, when new, will have so low a resistance that it will sometimes give as much as 30 amperes for a short time when short-circuited through a Weston ammeter. Another point of importance is that the resistance of a Weston voltmeter is so high that a small decrease in the resistance of the circuit, of which it forms a part, caused by bringing the plates closer together, will have too slight an effect to materially change the total current flowing under the conditions.*

* See also Gorton's "High School Physics," Chapter XVIII; Fuller and Brownlee's "Laboratory Exercises," Experiment 68; "Physics," Mann and Twiss, page 58; and "Physics Laboratory Manual," by Cavanagh, Westcott and Twining.   Ginn Company, Publishers, New York.

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